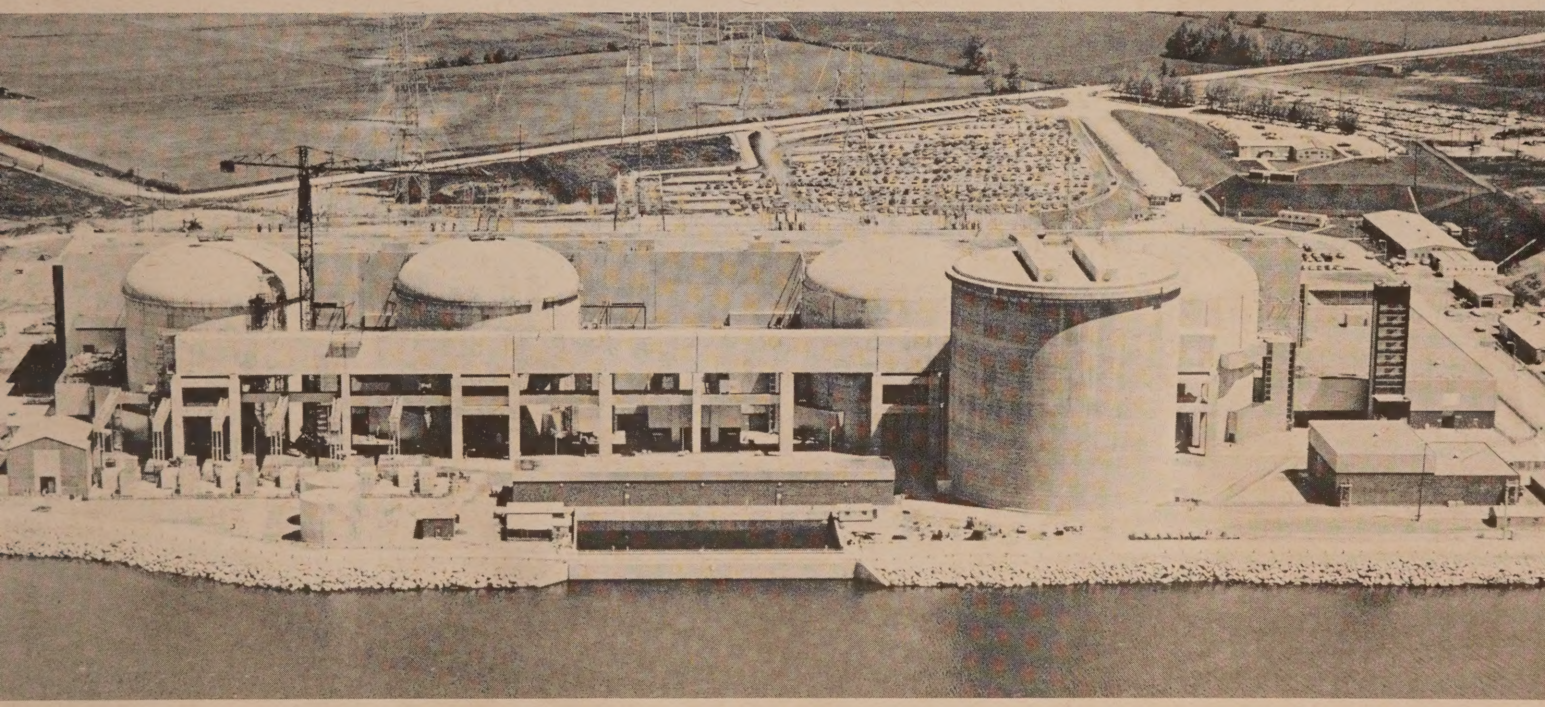
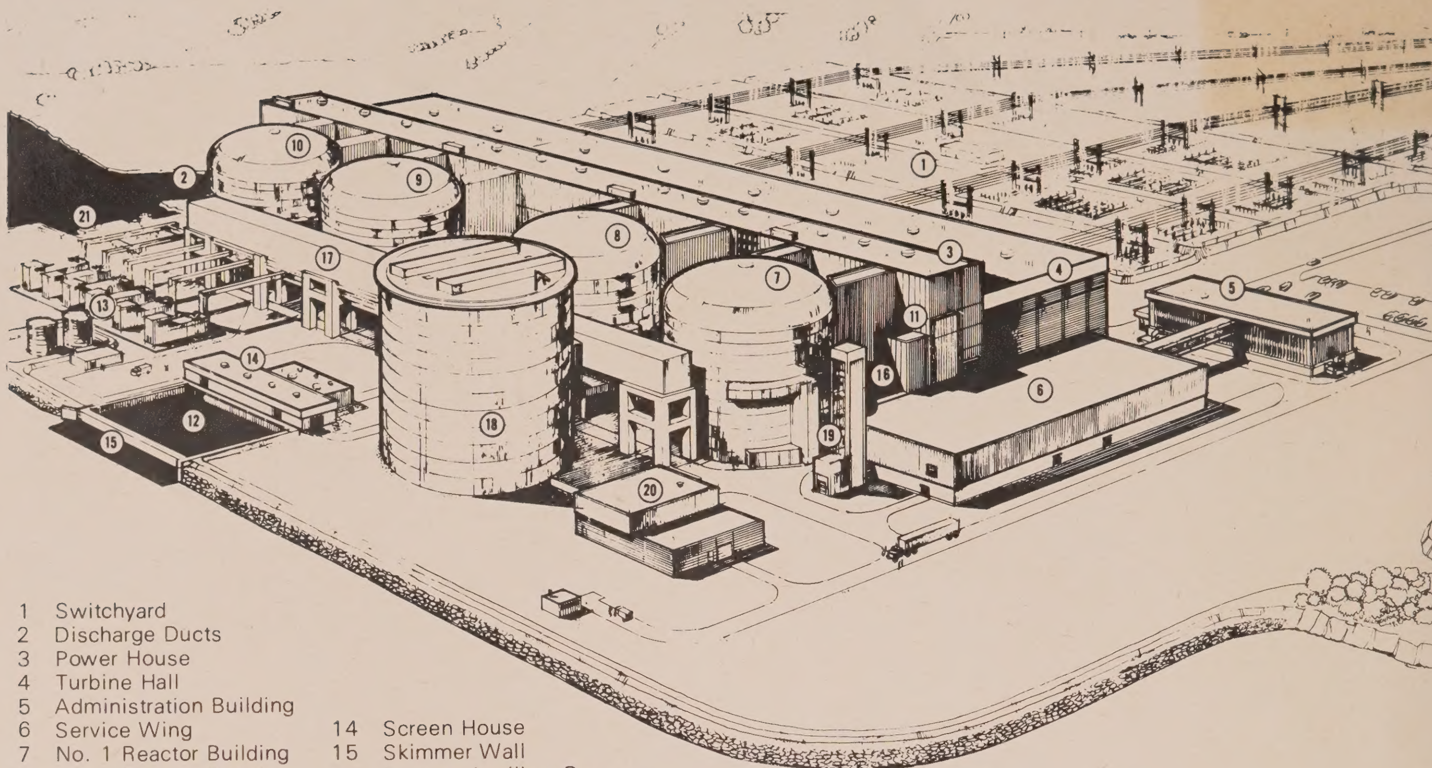
Hydro electric Power Commission

V/F

pickering generating station





1 Switchyard
2 Discharge Ducts
3 Power House
4 Turbine Hall
5 Administration Building
6 Service Wing
7 No. 1 Reactor Building
8 No. 2 Reactor Building
9 No. 3 Reactor Building
10 No. 4 Reactor Building
11 Turbine Auxiliary Bay
12 Intake
13 Auxiliary Power Units
14 Screen House
15 Skimmer Wall
16 Reactor Auxiliary Bay
17 Relief Duct
18 Vacuum Building
19 D_2O Upgrading Tower
20 Water Treatment Building
21 Barge Unloading Dock

Pickering in Perspective

One day in April, 1971, a steady flow of heat from billions of atoms splitting in a reactor produced steam to spin a turbine at Pickering Generating Station for the first time. When completed this station, on Lake Ontario east of Toronto, will have a capacity of 2,160,000 kilowatts — enough power to supply 1,700,000 homes. It will mark a major advance in Canada's efforts to produce electricity from nuclear energy at costs competitive with or cheaper than the fossil-fuelled plants now used to supplement hydro-electric resources.

Pickering's energy is expected to cost about the same as that from a coal-fired station of comparative size. The initial 464-ton fuel load for the station's four reactors is the energy equivalent of 10 million tons of coal, or enough to fill about 136,000 railway cars. Since the station uses natural or unenriched uranium, found in abundance in Ontario, it will greatly reduce the amount of coal required to meet demands for power which double about every 10 years. Without nuclear power, by 1980 Ontario Hydro's annual consumption of imported fossil fuels would climb to the equivalent of 35 million tons of coal costing $350 million a year.

Pickering, designed by Atomic Energy of Canada Limited and Ontario Hydro, will be one of the largest nuclear stations in the world. It is the first nuclear station built, owned and operated by a Canadian utility.

The first two 540,000-kilowatt units are being jointly financed by Ontario Hydro and the provincial and federal governments. Ontario Hydro will pay back with interest the governments' contributions and will bear the entire cost of the third and fourth units.

Construction started in 1965. At its peak, more than 3,000 persons were employed on the project. Contracts have been awarded to a wide range of Canadian companies who are meeting the exacting challenges to produce quality components for the station.

Pickering is Ontario's third nuclear-electric station based on the proven success of CANDU (Canadian Deuterium Uranium) reactors fuelled with natural uranium and moderated and cooled by heavy water. Nuclear Power Demonstration (NPD), a 20,000-kilowatt pilot plant on the Ottawa River near Rolphton, has operated successfully since 1962. The Douglas Point station, located on Lake Huron between Port Elgin and Kincardine, was started up in January, 1967, and is producing 200,000 kilowatts for Ontario's power system.

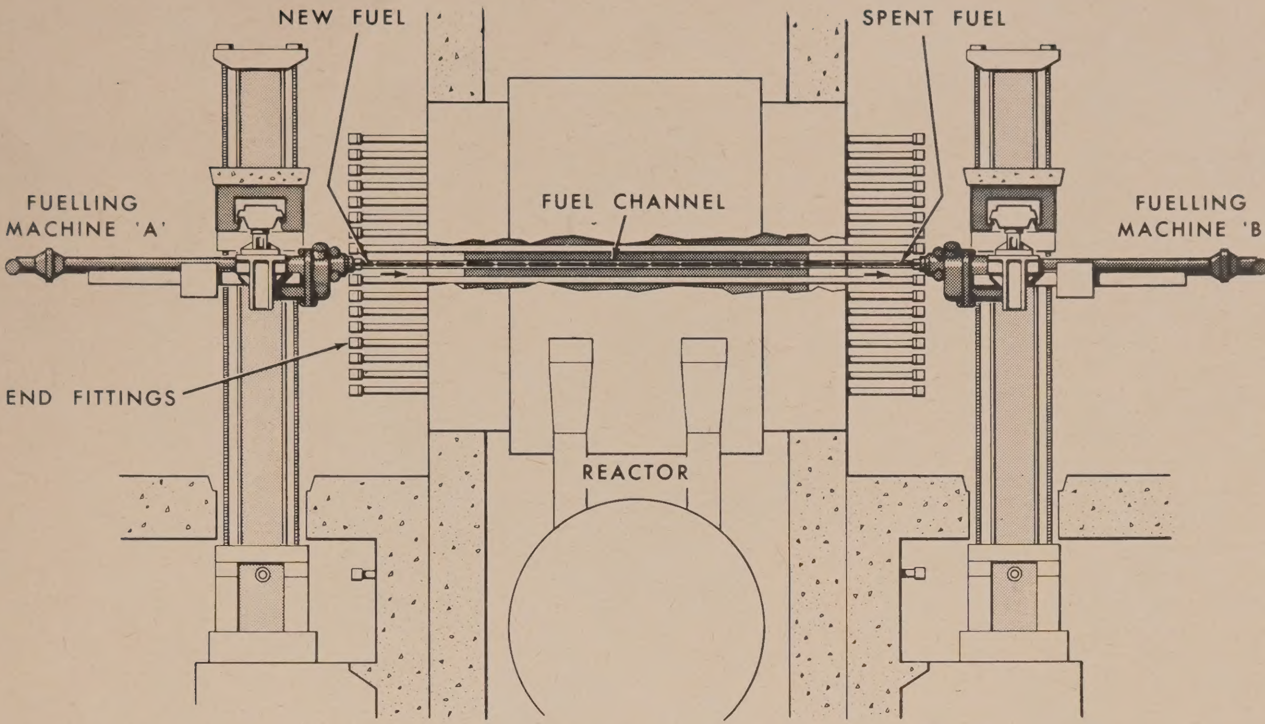
Pickering's 540,000-kilowatt units represent a large step forward in the quest to produce electric power from nuclear energy at prices competitive with other fuels. By achieving economies of scale made possible with large units, it is fully expected that nuclear-electric stations will be competitive as base load plants which supply power continuously to meet demands. However, hydro-electric and fossil-fuelled plants will still be necessary to meet power demands during peak periods. Nuclear plants will thus supplement conventional sources of electricity for Ontario's power system.

In 1945, Canada's first experimental reactor produced about as much heat as a light bulb. But as a step beyond Pickering, Hydro has decided to move up from 540,000 to 800,000-kilowatt units at the 3,200,000-kilowatt Bruce Generating Station being built next to the Douglas Point plant. Each of these larger units will supply enough power to serve a good-sized Ontario city.

Nuclear Fission

A nuclear reactor is simply a source of heat produced when uranium atoms split or fission. As in a coal-fired station, heat creates steam to drive the turbo-generators and produce electricity.

Natural uranium fuel contains one part of fissionable Uranium 235 to about 140 parts of Uranium 238. It is processed by a nuclear fuel manufacturer into cylindrical uranium dioxide fuel pellets about one-half inch in diameter which are sealed in thin Zircaloy tubes called elements or pencils. Zircaloy is a space-age alloy of Zirconium and tin which retains its strength at high temperatures and captures few neutrons. Pickering has 28-element fuel bundles, each 19.5 inches long and weighing



TWIN FUELLING MACHINES, CONTROLLED BY COMPUTERS, ARE USED FOR 'ON-POWER' REFUELLING. THE MACHINES HOME ON A REACTOR FUEL CHANNEL, MAKE A PRESSURE-TIGHT CONNECTION, REMOVE SEALING AND SHIELD PLUGS, INSERT AND REMOVE FUEL BUNDLES AND RECLOSE THE CHANNEL.

54.5 pounds. Each reactor core contains 116 tons of uranium dioxide (UO_2) consisting of 4,680 fuel bundles. The average life of a fuel bundle in the reactor will be between one-and-a-half and two years.

U238 is the commonest isotope of uranium. A U238 atom contains 92 electrons, 92 protons and 146 neutrons; U235 has the same number of electrons and protons but only 143 neutrons. When a U235 atom is struck by a slow or "thermal" neutron, it will split into two roughly equal fragments. Splitting is accompanied by a tremendous release of energy in the form of heat, radioactivity and two or three neutrons. These neutrons split other U235 atoms and support a controlled chain reaction.

Chain Reaction

However, not even a large amount of natural uranium by itself will sustain a nuclear chain reaction. Fast neutrons travelling at 26,000 miles per second must be slowed down or moderated to about one mile a second before fission will occur. The neutron's target is a U235 nucleus about a billionth of an inch in diameter.

Canadian reactors use heavy water as a moderator because ordinary water would absorb too many neutrons to sustain a chain reaction. Heavy water looks and tastes like ordinary water but contains heavy hydrogen or deuterium atoms which are twice as heavy as ordinary hydrogen atoms. Neutron speed is reduced by collisions with deuterium atoms, like a ball bouncing off others on a billiard table. A U235 atom captures the slow neutron, splits and releases more neutrons.

Heavy water, technically known as deuterium oxide (D_2O), occurs naturally as one part in 7,000 in ordinary water. Manufactured by a complex process, heavy water costs between $20 and $21 a pound. Each Pickering reactor contains 488 tons of heavy water, both as a moderator and as a hot fluid in the heat transport system.

Controlling the Reaction

A chain reaction can be maintained only if the system exceeds a certain size, known as the critical mass, because neutrons are lost either through capture by other atoms or by the steel and concrete containment structure. As indicated previously, this mass is 116 tons of uranium for each Pickering reactor. The reactor becomes critical when a steady chain reaction is taking place.

The principle ways of controlling the reaction during start up or shut down are by adjusting the level or volume of heavy water in the reactor or by raising or lowering steel shut-off rods as a fail-safe procedure, the reactor can be shut down completely within 30 seconds by releasing the moderator through ports into a dump tank located under the containment vessel or calandria.

Heart of Reactor

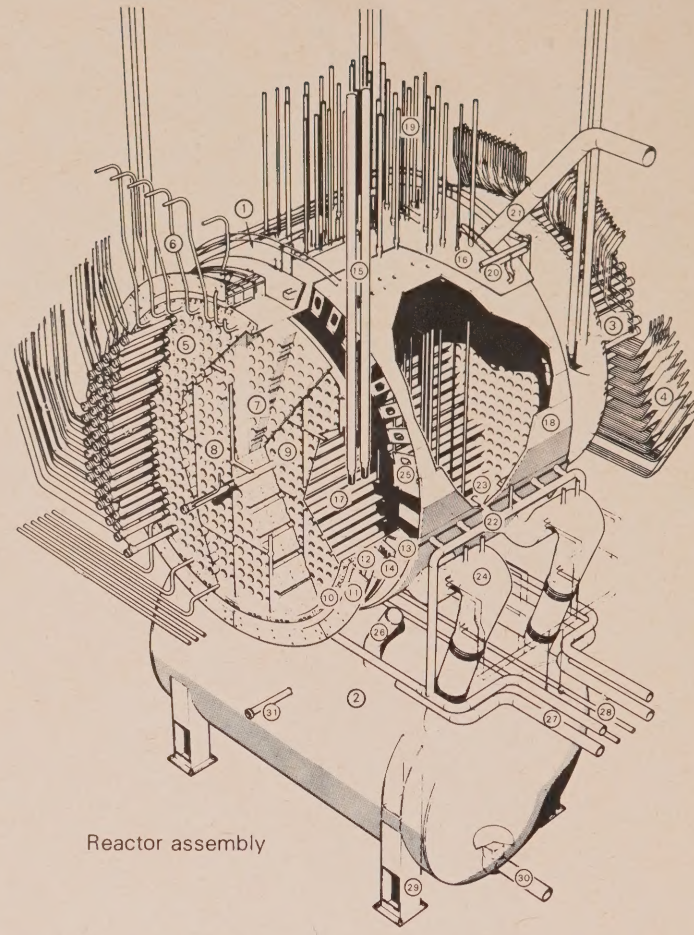
The calandria, a stainless steel cylindrical vessel about 26½ feet in diameter and 27 feet long, is the heart of the reactor. It weighs approximately 665 tons exclusive of fuel and the moderator. Its internal peripheral thermal shell shields are 4½-inch stainless steel slabs positioned close to the cylinder walls. At each end are combination heat and radiation shields. The end shields, nearly four feet thick, consist of steel slabs and plates with provision for two 2½" thick layers of cooling water. Inside the calandria are 25 spray nozzle clusters to provide a drenching spray throughout the entire interior of the calandria to cool continuously any part not covered by the moderator. The spray cools exposed metal parts which heat up because of radiation during operation and shutdown periods.

The dump tank, a horizontal cylindrical stainless steel vessel about 38 feet long and 18 feet in diameter, is connected to the calandria by four dump ports. During operation, helium gas in the dump tank is held at a pressure in excess of that in the top of the calandria. When the pressure is equalized the moderator is dumped by gravity into the dump tank.

Fuel Channels

The calandria contains 390 horizontal tubes or fuel channels surrounded by the heavy water moderator. Each fuel channel consists of 12 fuel bundles in a Zircaloy pressure tube

1 Calandria
2 Dump Tank
3 End Fittings
4 Feeders
5 End Shield Outer Tube Sheet
6 End Shield Cooling Inlets and Outlets
7 End Shield
8 Baffles
9 End Shield Inner Tube Sheet
10 End Shield Key Ring
11 Anchor Plate
12 End Shield Ring
13 Ring Thermal Shield
14 Cooling Pipes
15 Calandria Support Rods
16 Calandria Shell
17 Calandria Tubes
18 Calandria Shell Shields
19 Control and Shut-off Rods
20 D_2O Spray Cooling
21 Helium Balance and Blow off lines
22 D_2O Inlet Manifold
23 D_2O Inlet Nozzles
24 Dump Ports
25 Shell Shield Support Plates
26 Helium Balance Line
27 D_2O Outlet
28 Dump Port & Dump Tank Spray Cooling Lines
29 Dump Tank Supports
30 Dump Tank Drain Line
31 Rehearsal Facility



Reactor assembly

terminating in stainless steel end fittings with removable plugs providing access for refuelling. Zircaloy calandria tubes separate the pressure tubes from the moderator.

Cooled nitrogen gas is pumped through a sealed annulus — the space between the calandria and pressure tubes — to insulate the moderator from the heavy water coolant flowing over the hot fuel bundles in the pressure tubes.

Tubes are made from Zircaloy and their thickness is kept to a minimum for neutron economy. For example, the thickness of the individual fuel pencil sheaths varies between 15/1,000th and 19/1,000th of an inch.

Heavy water, pressurized to prevent boiling, is pumped through the pressure tubes to transport heat from the fuel to the steam generator, a system of 12 tube-in-shell heat exchangers. This heavy water leaves the reactor at a temperature of 560 degrees Fahrenheit and a pressure of 1,280 pounds per square inch. After transferring heat to ordinary water in the steam generator, the heavy water is piped back to the reactor in a continuing cycle. The heavy water heat transport fluid thus circulates in a closed system, separated from both the moderator system in the reactor and from the ordinary water system in the steam generator. Steam is collected in a steam drum and piped to the turbo-generator at 483 degrees F. and 585 p.s.i.

Pickering's four units will require 1,250,000 gallons of Lake Ontario water a minute for cooling purposes. The cooling water circulates in a closed system through miles of tubing in the condensers and is returned to the lake in pure condition but about 18 degrees warmer than the average intake temperature of 52 degrees.

On-Power Fuelling

One of the features of Canadian reactors is on-power fuelling. Two co-ordinated fuelling machines, controlled by computers in the station control centre, load new fuel and remove spent fuel. These machines operate through a semi-automatic program: homing on a reactor fuel channel, making a pressure-tight connection, removing sealing and shield plugs, inserting and removing fuel and reclosing the channel.

When the reactor is operating in its designed output range (80 per cent load factor), an average of nine fuel bundles is inserted by the machines per day. During their stay, fuel bundles are moved in a planned sequence to various parts of the reactor to ensure efficient burnup. This procedure contributes to high neutron economy and fuel burnup which results in the lowest fuelling cost of any reactor system.

New fuel is introduced by hand to a magazine which transfers it to the fuelling machine. A spent fuel bundle is discharged from the fuelling machine to a spent fuel mechanism which, in turn, transfers it by conveyor to the station's spent fuel storage bay. Here, it is stored under 26 feet of water until sale or disposal. The storage bay, lined with 14-inch thick concrete walls and a 12-inch floor, both steel-reinforced, is located within the main structural concrete of the reactor auxiliary bay. The double wall is specially treated to prevent leakage of water. But if any seeps through, it is drained away to manholes for cleanup and returned to the bay, which provides enough space to hold spent fuel for approximately 42 reactor years.

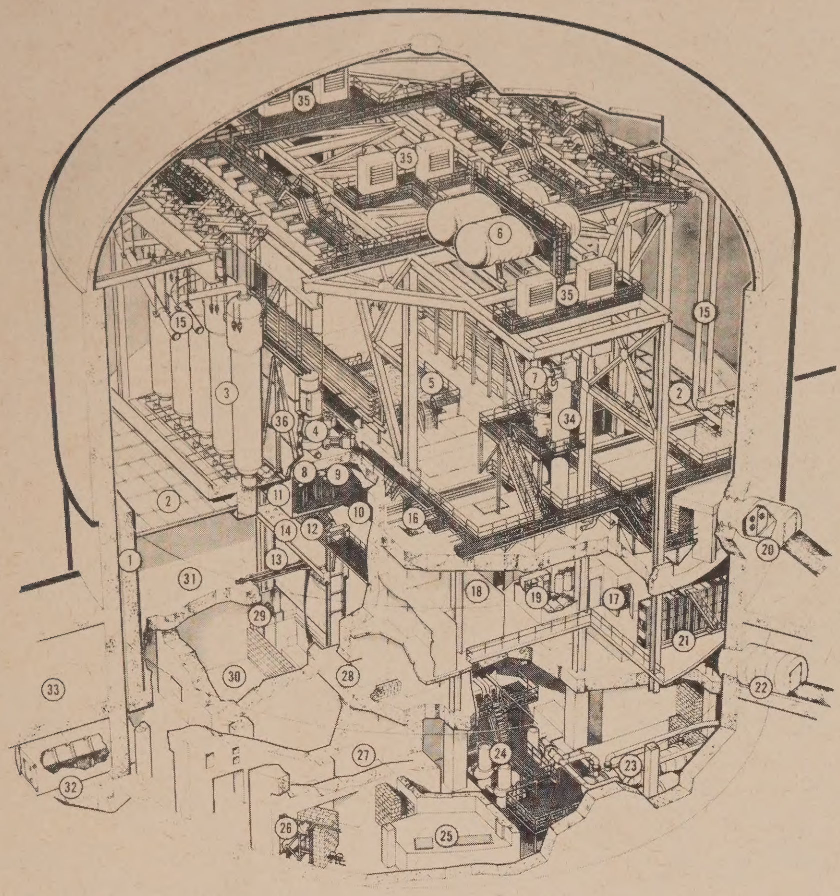
Shielding

Pickering is designed to protect the public and station personnel from alpha, beta and gamma radiation by extensive shielding, containment and plant zoning. Alpha particles, consisting of two protons and two neutrons corresponding to the nucleus of a helium atom, can't penetrate paper or skin.

Beta particles — electrons emitted from nuclei through radioactivity — travel several yards through the air and can penetrate one-third of an inch of tissue. Gamma rays — short-wave radiation somewhat like X-rays — travel hundreds of feet through the air and can penetrate many inches through tissue or solid matter. Safety is ensured by shielding, distance from the source of radiation and limiting exposure time.

Reactor Building

The reactor building supports and encloses the reactor and directly associated equipment, shields personnel from radiation and, in conjunction with the vacuum building and pressure relief ducts, contains any radioactivity which might be released.



Cutaway view of reactor building looking south-west

1 Pressure Walls
2 Blowout Panels
3 Steam Generators
4 Primary Heat Transport Pumps
5 Control and Shut-off Rods
6 Feed Water Reserve Tanks
7 Boiler Room Crane
8 Primary Heat Transport Reactor Outlet Header
9 Primary Heat Transport Reactor Inlet Header
10 Feeder Pipes
11 Feeder Insulation Cabinet
12 Reactor End Fittings
13 Fuelling Machine Head
14 Fuelling Machine Bridge
15 Main Steam Supply Pipes
16 Pipe Chase
17 Instrumentation Room (West)
18 D_2O Collection Room
19 Zone Control System Room
20 Boiler Room Airlock
21 Reactor Control Distribution Frame
22 Main Equipment Airlock
23 Moderator Heat Exchangers
24 Moderator Pumps
25 Moderator and Ion Exchange Columns
26 Spent Resin Drying Tank
27 Fuelling Machine Auxiliaries Room (East)
28 Fuelling Machine Vault Doorway
29 Fuel Transfer Port
30 Fuelling Machine Service Room (East)
31 Fuelling Machine Vault (East)
32 Fuelling Machine Airlock
33 Reactor Auxiliaries Bay
34 Bleed Condenser and Bleed Cooler
35 Boiler Room Cooling Units
36 Shielding Wall

The reactor building, about 140 feet in diameter and 153 feet high, has concrete walls four feet thick. Access is only through airlocks. Pressure inside the building is maintained slightly below atmospheric pressure so that air tends to penetrate the walls rather than leak out. To ensure leak-tightness, the internal concrete surface was coated with epoxy grout before painting.

Inside, the reactor building is a massive concrete structure of walls and floors, some of which are more than four feet thick. The calandria vault is an independent box-life structure of heavy concrete which contains the calandria and dump tank. Thickness of the concrete walls varies between four and 11 feet. This concrete shielding is cooled by a network of pipe coils in which ordinary water is circulated. Thus the reactor is shielded by its heavy concrete box — made with ilmenite ore aggregate — as well as the interior and exterior walls of the reactor building. Some parts of the building are inaccessible during operation; access is restricted in other areas to essential personnel.

Reactor Auxiliary Bay

This conventional two-storey, steel-frame building fits around the northern halves of the four reactor buildings. The spent fuel storage bay described earlier is on the ground floor between the second and third reactor buildings. On the second floor is the station control centre for the four units. Also located there will be heavy water cleanup and evaporation equipment for the upgrading tower east of the first reactor building. A second and larger heavy water upgrading plant is being built at the western end of the station. Efficient recovery and re-use of heavy water will help to reduce operating costs.

Powerhouse

This building, 1,000 feet long, 210 feet wide and 124 feet above grade, consists of the turbine hall housing the generating equipment and the turbine auxiliary bay for overhaul and repair work. The turbines are tandem compound units consisting of a double-flow, high pressure cylinder and three low-pressure cylinders.

Service Wing

The two-storey service wing, large enough to service an eight-unit station, is attached to both the powerhouse and reactor auxiliary bay. Waste disposal facilities are housed in the basement. The first floor provides space for workshops, repair of fuelling machines and overhaul of contaminated equipment. The second floor has facilities for cleanup of station personnel, decontamination of plastic and rubber goods, a laundry, workshops, laboratories and offices. A radiation monitor, the last one between zoned and unzoned work areas of the station, is located on the bridge joining the service wing and the administration building.

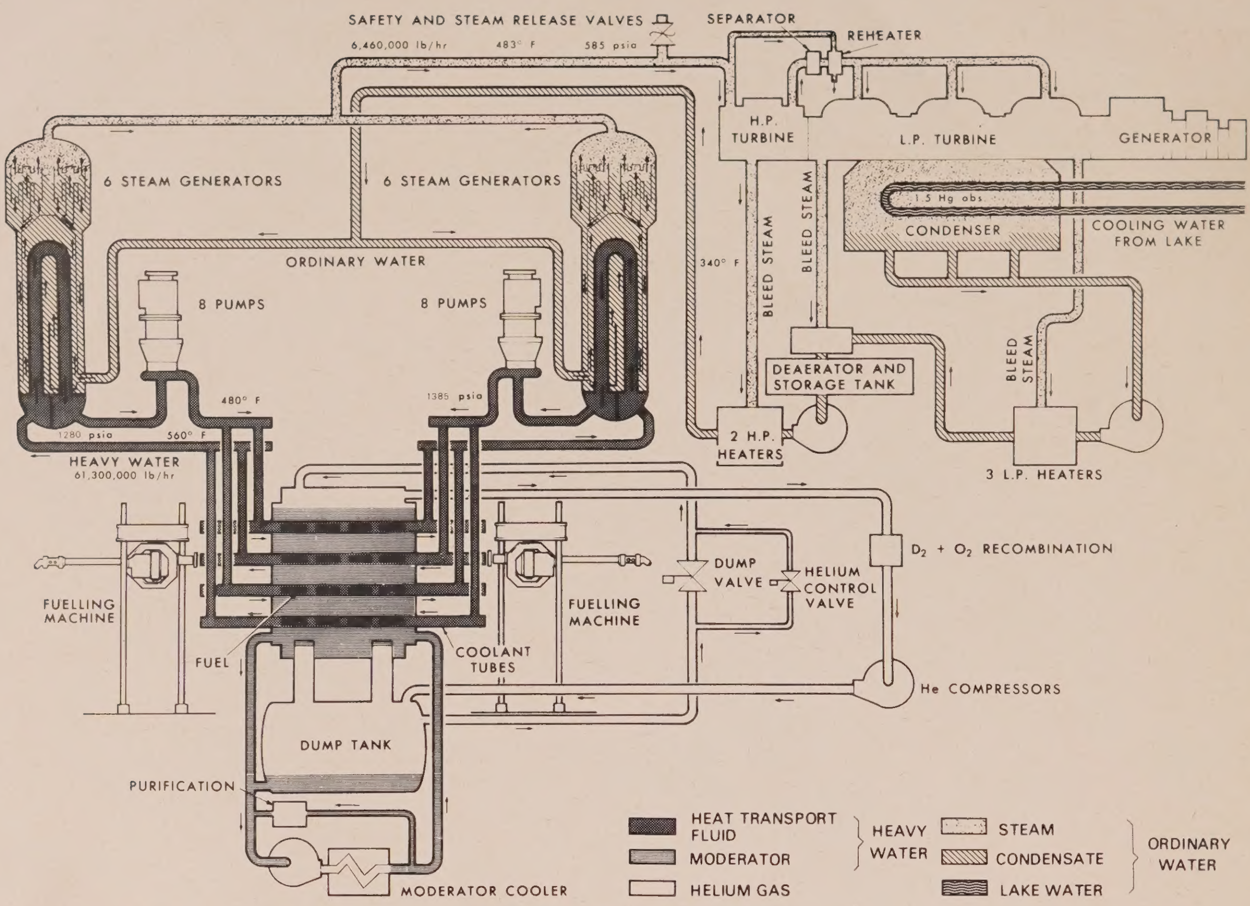
Vacuum Building

The reinforced concrete vacuum building with its internal concrete frame is a key part of Pickering's containment system. It is supported by about one thousand 50-foot steel piles driven to bedrock and has an inside diameter of 165 feet and internal height of 166 feet. Walls are three feet thick and the roof is a two-foot thick reinforced slab. Interior concrete columns are four feet in diameter with tie beams two feet wide and four feet deep.

Directly under the roof is a concrete storage tank 153 feet in diameter and about 20 feet high which contains more than 2,000,000 gallons of water. The four reactor buildings are connected to the vacuum building by a reinforced concrete pressure relief duct about 20 feet wide and 25 feet high.

Pressure in the containment system is kept below atmospheric so that leakage will be into the containment structures.

In event of any accident in the reactor building which causes pressure to rise to a positive pressure of 1.0 p.s.i., pressure relief valves will open to relieve pressure through the ducts to the vacuum building in less than 30 seconds. The maximum single incident which the pressure relief system is designed to accommodate is a sudden piping failure equivalent to the complete severance of a reactor inlet header which would result in the complete loss of heavy water heat transport fluid in a matter of minutes.



SIMPLIFIED STATION FLOW DIAGRAM

The vacuum building is capable of containing all steam produced by the discharge of the entire heat transport system without the need for a dousing spray from the water tank. However, the dousing spray will come on automatically at a pressure of six pounds per square inch to cool the air and condense any steam present. Thus the vacuum building and pressure relief system are collectively designed to contain all the energy that could be released inside a reactor building following any conceivable accident to the reactor or heat transport system, and to provide complete protection for the public.

Control System

Electronic digital computers control and check all regulating mechanisms governing reactivity — the amount a reactor is above or below criticality. Two computers are used for each 540,000-kilowatt unit with the second computer providing a complete backup for important control functions performed by the first computer. Each computer, however, has its own functions.

Computers monitor temperatures of the 390 fuel channels once every two seconds, control reactor power and boiler pressure, operate fuelling machine and fuel transfer controls and automatically start up the turbine. Other functions include alarm recording, data logging and sequence of event recording timed to the accuracy of a few milliseconds.

Several reactivity control devices are monitored by computers. These include neutron-absorbing cobalt adjuster rods, shut-off rods, light water zone control, moderator level and boron injection. Boron dissolved in heavy water is added to the moderator to capture neutrons and suppress excess reactivity which is beyond the capacity of other systems. The boron is removed by an ion exchange system when necessary.

To ensure safe, efficient operation, Pickering has a triplicated protective system. As prviously mentioned, Pickering's shutdown mechanism includes 11 cadmium-steel shut-off rods and the gas balance moderator system. The moderator is dumped if the shut-off rods fail to reduce neutron power at a predetermined minimum rate when a shutdown signal occurs or if the reactor power becomes appreciable when the shut-off rods are inserted. Nuclear engineers say there is a probability neither of these needs will arise during the life of the plant.

Radiation Protection

To understand radiation protection, we need to be familiar with two terms. The first is the term "r" for roentgen, the unit used to measure the amount of ionization produced in air by X-rays or gamma radiation. The second term is "rem" - the quantity of any radiation which will have the same biological effect on man as the exposure to one roentgen of X-rays.

We are all exposed normally and continuously to alpha, beta and gamma radiation. Some is even contained in the body tissues, but the environment contributes most of it in the form of gamma rays from the earth and radiation from outer space. This total amount of background radiation amounts to about 0.125r per year and increases with altitude due to the increase in cosmic radiation.

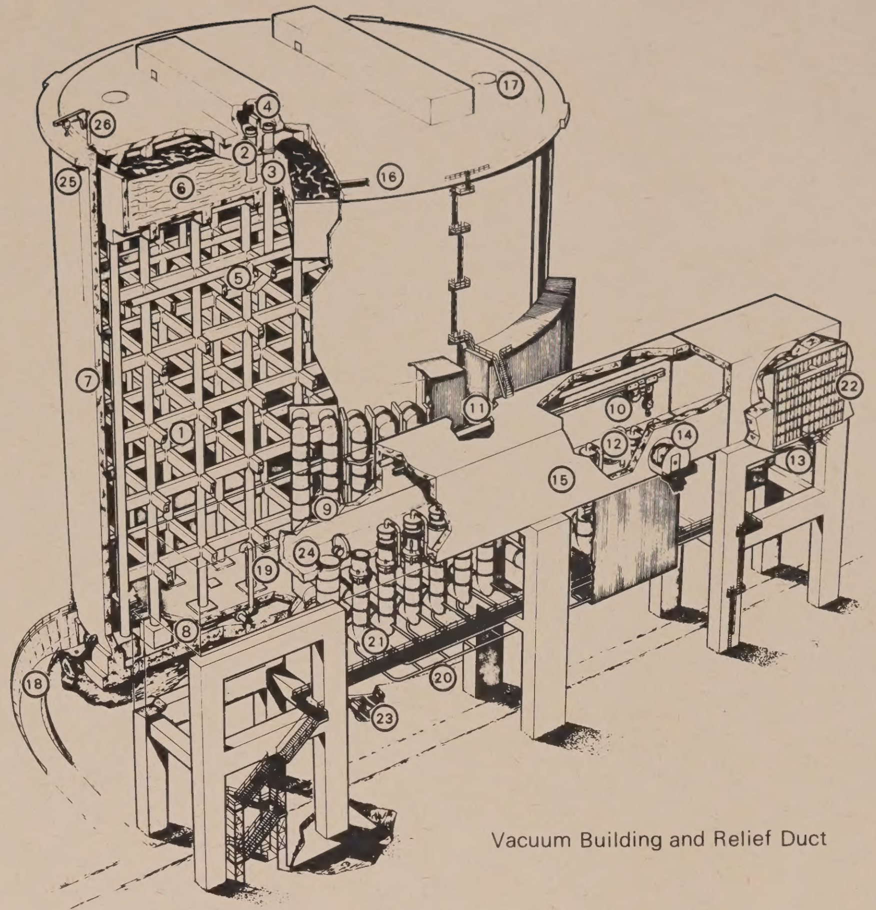
The level is about twice as high in mountainous areas as at sea level. If you live in a granite building, the background dose may be doubled because of radiation from the stone. In fact, a geiger counter will start to click on any sidewalk.

Since humans and all other species have been subject to such normal radiation throughout history, this amount has been used as an important guide in developing radiation protection standards. An ordinary chest X-ray gives up to 2rems. About 450 rems may prove lethal. The recommended average annual exposure limit for radiation workers is 5 rems. For individual members of the public, the recommended limit is 0.5 per year, but in practice the maximum exposure to any member of the public has been about one per cent of this figure.

Experience to date shows that someone in the neighbourhood of a nuclear-electric plant might receive an added annual radiation exposure of about 5/1,000ths rem a year. This is just about what a passenger would receive on a round-trip flight between Toronto and Vancouver.

Extensive precautions have been taken at Pickering to protect

1 Vacuum Building Internals
2 Pressure actuated water displacement system inlet header
3 Pressure actuated water displacement system outlet header
4 Vacuum Chamber
5 Distribution and Spray Header
6 Emergency Water Storage Tank
7 Perimeter Wall
8 Basement
9 Vacuum Ducts
10 Monorail and Hoist
11 Emergency Water Line
12 Pressure Relief Valves
13 Shielding Walls
14 Personnel Airlock
15 Pressure Relief Duct
16 Roof/Wall Seal
17 Water Tank Access Hatch
18 Basement Access Ramp
19 Vacuum Pump Suction Header
20 Vacuum Duct Drain Pipe
21 Vacuum Duct Fill Pipe
22 Reactor Building Pressure Relief Louvres
23 Services Tunnel
24 Equipment Airlock
25 Perimeter Wall Monorail
26 Jib Crane



Vacuum Building and Relief Duct

both public and station personnel from radiation hazards. All effluents, liquid and gaseous, are continuously monitored and controlled. For example, small amounts of solid wastes are concreted in steel drums and stored underground while awaiting disposal. Ground water is regularly checked to ensure there is no seepage of wastes.

The plant is divided into three zones according to the potential radiation hazard and access is restricted to certain areas. Station staff are provided with protective clothing and air masks where necessary and use decontamination facilities in the service wing. Radiation is monitored by a system of fixed and portable units throughout the station. Strict operational procedures govern movement of personnel and equipment in areas where hazards may occur.

Staff Training

Pickering requires a staff of about 280 persons, including engineers, chemists, physicists, technicians, control and mechanical maintainers, operators and clerical staff. After intensive training at Hydro's Nuclear Training Centre at Rolphton, Ontario, personnel are assigned to either NPD or Douglas Point Generating Stations for a combination of on-the-job and classroom training.

All levels of training stress radiation protection, safe handling of chemicals and safe work practices. To qualify for supervisory positions — first operator, control room operator and shift supervisor — candidates must pass exams set by Ontario Hydro and the Federal Government's Atomic Energy Control Board. Personnel are retested from time to time as part of the program of continuing training. As Ontario Hydro's nuclear-electric program expands, many career opportunities will be created in the province.

In Quebec, a 250,000-kilowatt nuclear station, which used boiling light water in place of pressurized heavy water as heat-transfer medium, is in operation. In a wider context, it's estimated that by the year 2000 heavy water-moderated stations will supply half of Canada's annual electric demand of one trillion kilowatt-hours.

The Future

The economic benefits for Canada will be substantial. An AECL spokesman has estimated that Canadian-designed heavy water reactors will save the country some \$7 billion by the end of the century. In addition, Canada will have benefitted by a further \$12 billion through savings on imported fossil fuels which would otherwise have been needed.

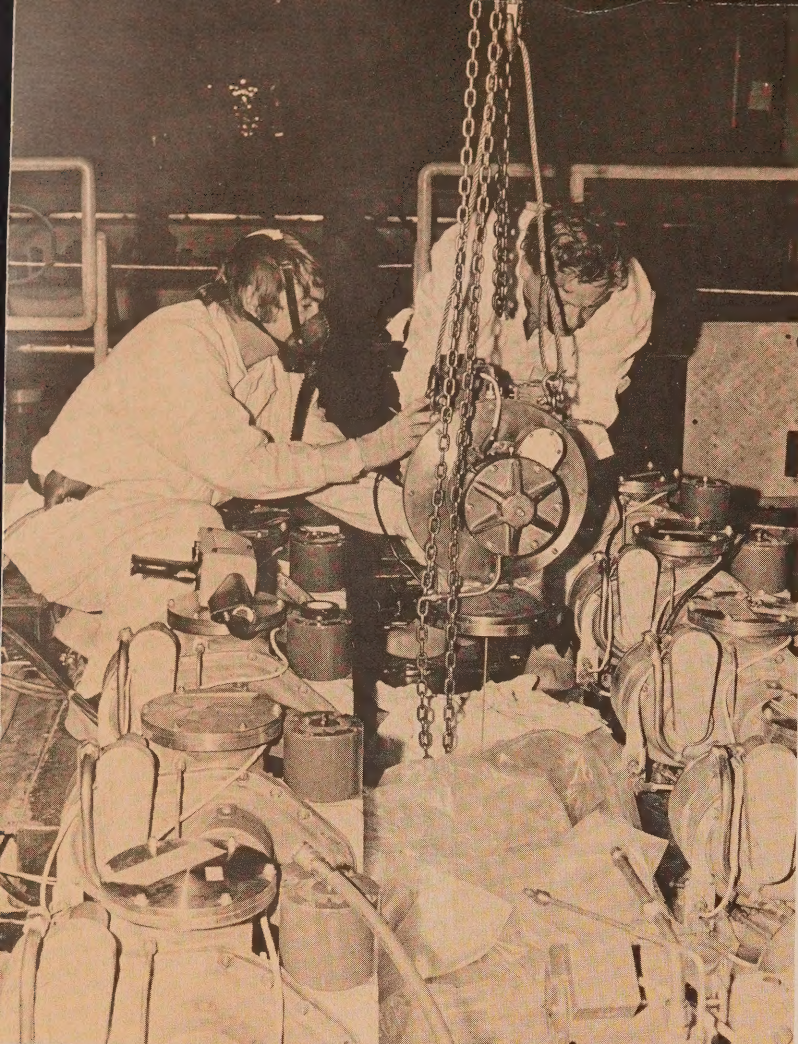
Pickering has already opened up opportunities for many Canadian companies to enter the nuclear power field and develop technology both for domestic and export purposes. Besides producing electricity economically, the station will produce radioactive isotopes for a growing number of uses in medicine, agriculture, industry and fisheries research. In the years ahead, new applications will doubtless affect our lives in many ways.

In a rapidly-changing world it's unlikely that Pickering will be the last word in nuclear technology. Around the world, researchers are hard at work on breeder reactors, which create more fissionable material than they consume, and on trying to achieve extremely high temperatures necessary to fuse heavy hydrogen atoms and release controlled energy to produce electricity.

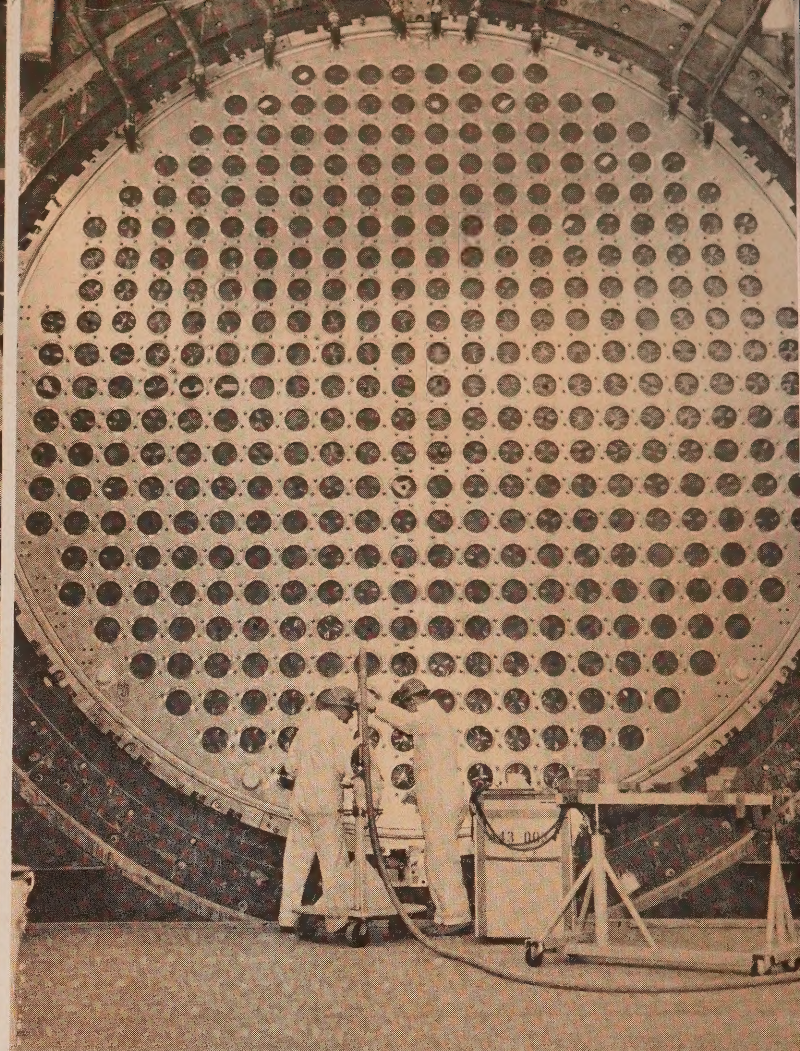
It has been estimated that one per cent of the deuterium in the oceans could supply world energy needs for millions of years. But whatever developments may come, Canada is in the forefront of nuclear developments and in a good position to make an important contribution to the world's nuclear programs.

The outstanding characteristic of the CANDU system is its remarkable flexibility. Besides natural uranium Pickering could use enriched fuel, plutonium or a combination of elements without shutting down the reactor. Light boiling water could be used instead of pressurized heavy water for heat transport. Spent fuel from CANDU plants could feed breeder reactors if they become economical in the next decade.

Indeed, Pickering is a pathfinder for peaceful uses of nuclear energy which has virtually unlimited potential to sweep open new horizons around the world.



Crew adjusts reactor controls



Reactor channels readied for fuel

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